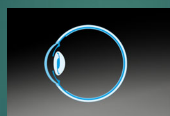
What's New in Biometry and IOL Formulas?

2022 Southern Eye Congress, July 21-24, 2022



KAMRAN M. RIAZ, MD
CLINICAL ASSOCIATE PROFESSOR OF OPHTHALMOLOGY
DIRECTOR OF MEDICAL STUDENT RESEARCH
CATARACT, CORNEA, EXTERNAL DISEASE AND REFRACTIVE SURGERY
DEAN MCGEE EYE INSTITUTE, UNIVERSITY OF OKLAHOMA
KAMRAN-RIAZ@DMEI.ORG

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Financial Disclosures

- I have no financial interests in this lecture or any information discussed therein
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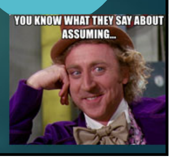
- Jacob Rogers, MS4 – OU College of Medicine

Objectives

- To summarize recent developments in optical biometry technology
- To review philosophical approaches of currently-available IOL formulas
- To survey various resources available for improving our outcomes

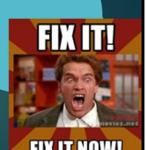
Introduction

- We use assumption models of the phakic eye to obtain information about the pseudophakic eye
- George Box (British statistician): "all models are wrong, but some are useful"
- These models are pretty good in normal eyes…



Introduction:

- Modern cataract surgery = refractive surgery
- Plethora of new IOLs, new machines, new devices, etc.… Yet:
- Accuracy:
  - Within 0.5D? Hill review (260,000 eyes) - majority clustered around 78% (based on older formulas)
  - Melles (Ophthalmology 2019) :
    - best formulas are 70% accurate within 3/8 diopter; much worse in short AL eyes
    - Every formula still has eyes with prediction errors over a diopter.
  - Why are we still so inaccurate?
- There's a big push to fix the problem during or after surgery
  - During: FLACS, ORA
  - After: Excimer laser, Light adjustable lens
  - Sounds good to improve outcomes in high socio-economic class patients
- But what if we did the work before surgery smarter?
  - Better understand: 1) biometry measurements, 2) IOL geometry (and optimized constants) and 3) IOL formulas → Provide good outcomes for all patients regardless of financial status



Biometry Measurements

- Measurement of AL remains one of the most crucial steps in IOL power calculation
- SRK Formula is useful model
- AL is the most heavily weighted factor

$$P = A - 0.9K - 2.5L$$

Biometry Measurements

- Compared to other parameters (K-readings, ACD, etc.), errors in AL are the most "devastating" errors in IOL power calculations

Variable	Error	IOL Calculation Error
AL	1.0 mm	2.5-2.7D
K-readings	1.0 D	0.9-1.2D
ACD	1.0 mm	1.5 D
Wrong IOL Placed	1.0 D	0.67D

Long AL, Silicone Oil, Etc
Measured AL is falsely longer

$$\downarrow P = A - 0.9K - 2.5L \uparrow$$

RISK OF HYPEROPIC SURPRISE

Short AL
Measured AL is falsely shorter >> longer

$$\downarrow\uparrow P = A - 0.9K - 2.5L \downarrow\uparrow$$

RISK OF MYOPIC >> HYPEROPIC SURPRISE

Why Are AL Measurements Difficult?

NORMAL AL EYES

- Ultrasound biometry (USB): cornea → ILM; optical biometry (OB): cornea → RPE
  - Measurements by OB: AL measured as "too long" in long AL eyes and "too short" in short AL eyes

LONG AL EYES

- The fovea is often located on the side of a staphyloma rather than the bottom (limitation of USB)
- With OB, signal spends "more time" traveling in the vitreous → gets slowed down → longer time to return → falsely long AL → calculate a lower-than-needed IOL power → hyperopic surprise
  - Controversial: Haigis calibrated OB wrong, which is more inaccurate in long AL eyes (next slide)

SHORT AL EYES

- Proximity of the IOL to the retina; small change in ELP → higher effect on refractive accuracy
- IOL ELP often ends up more anterior, especially with shallow pre-op ACD → myopic (not worst thing!)

- Take home: err on the side of residual myopia for long AL, can safely aim for close to emmetropia for short AL given the tendency for a myopic surprise (esp. with old formulas)

Haigis Was Wrong(!)

Immersion Ultrasound Biometry vs. Optical Biometry

Cooke, David L. MD[1,2]; Waldron, Rhonda MMSc[3]; Savini, Giacomo MD[4]; Riaz, Kamran M. MD[5]; Taroni, Leonardo MD[6]; Murphy, David A. MD[5]; Guaraldi, Fabio MD[6]

Author Information

Journal of Cataract & Refractive Surgery: November 9, 2021 - Volume - Issue - doi: 10.1097/j.jcrs.0000000000000865

- Haigis original OB calibration[1]: unable to determine segment lengths (e.g. cornea, aqueous, lens, or vitreous) because this device (IOLMaster, Carl Zeiss) could only locate two points on the eye: the anterior corneal surface and the retinal pigment epithelium.
- He chose to calibrate it to segmental Immersion USB (IUSB)
- Convincingly, he found the same answer twice, with two different IUSB devices
- Two reasons he could have been wrong:
  - Alignment errors in A-scans
  - Assumptions by his IUS devices abt cornea
- Our findings: significant difference b/w IUS and OB using 4 diff datasets, diff IUS and OB machines from different international ophthalmic practices
- Major finding:
  IUSB AL is shorter by 0.0873mm c/w OB

Table 2 Comparison of optical AL vs immersion ultrasound AL from datasets in Figure 1

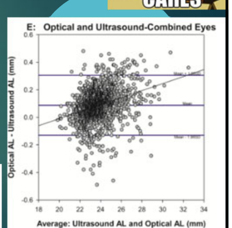
Dataset	Instruments (Optical Biometry vs. Immersion Ultrasound Biometry)	# of eyes	Optical AL longer by (mm)	LoA (mm)
1	OB 2 vs USB 1	946	0.0892	-0.1378, 0.3161
2	OB 3 vs USB 2	102	0.1012	-0.1078, 0.3101
3	OB 5 vs USB 4	656	0.0909	-0.1255, 0.3074
4	OB 4 vs USB 3	266	0.0661	-0.1137, 0.2460
5	Combined Data from Sets 1-4	1,970	0.0873	-0.1300, 0.3045

LoA is Limits of Agreement. OB is Optical Biometer. USB is Ultrasound Biometer. P-value < 0.001 for all comparisons between optical and immersion ultrasound axial lengths

1. Haigis W, Lege B, Miller N, Schneider B. Comparison of immersion ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to Haigis. Graefe's Arch Clin Exp Ophthalmol 2000;238:765-73.

OK, but who cares about 0.0873mm

- Slope in the trend line: EVEN MORE inaccuracy with short and long AL eyes. Specifically, after adjusting for the bias, compared to IUS ALs, OB-measured ALs were too long for long eyes and too short for short eyes.
- This same relationship has been found when comparing measured-optical OB AL to IUS, modified OB measurements, and sum-of-segments (SOS) AL



Optical Biometry	IUS (Recalc)	W-K Holladay 1_{2011}[1]	W-K Holladay 1_{2018}[2]	Sum-of-Segments[3]
20.00	20.00			20.14
25.00	24.89	24.91		24.95
26.50	26.35	26.23	26.35	26.40
30.00	29.78	29.31	29.21	29.76
34.00	33.69	32.84	32.48	33.61

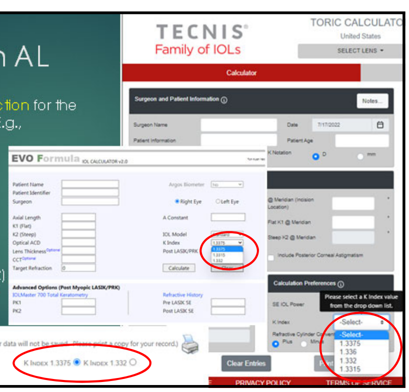
What can we do to improve AL measurements?

Accurate Axial Length

- Displayed Optical AL is too long in long eyes compared to
  - Ultrasound AL (previously discussed)
  - Sum-of-Segments AL
  - CMAL
  - Argos AL
  - New Holladay 1 AL
  - New Holladay 2 AL
  - Wang-Koch Adjusters
- (It's also too short in short eyes for some of these)

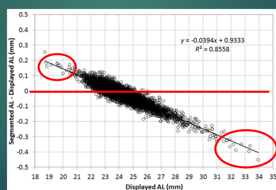
Inaccuracy with AL

- We use an assumed index of refraction for the entire eye based on eye models (E.g., Gullstrand, Liou-Brennan, etc.)
- Numbers vary:
  - 1.3375
  - 1.336
  - 1.3315
  - 1.332
- Limit: same index of refraction (IOR) used for all optical elements in eye



Accurate Axial Length

- Sum of segments (SOS): measuring the AL according to the IOR of major optical elements in the eye – cornea, aqueous, lens, vitreous
- SOS-AL does not equal the displayed AL with current OB techniques!
  - Especially not equal at short and long ALs



Wang L, Cao D, Weikert MP, Koch DD. Calculation of Axial Length Using a Single Group Refractive Index versus Using Different Refractive Indices for Each Ocular Segment: Theoretical Study and Refractive Outcomes. Ophthalmology. 2019 May;126(5):663-670. doi: 10.1016/j.ophtha.2018.12.046. Epub 2018 Dec 31. PMID: 30605743.

Accurate Axial Length

- Can't we just add up the CCT, ACD, LT, etc. and apply the IOR to each segment??
- Vitreous is not listed so you can't just sum the printout segment
- Cooke Modified Axial Length (CMAL): attempt to incorporate SOS using available measurements generated by optical biometry devices with current technology (OLCR biometer – Lenstar LS 900, Haag-Streit)
  - CMAL = 1.23853 + 0.9585 × Displayed axial length – 0.05467 × lens thickness
  - CMAL improved predictions with HQ, H1, SRK/T and H2 formulas

Cooke DL, Cooke TL. Approximating sum-of-segments axial length from a traditional optical low-coherence reflectometry measurement. J Cataract Refract Surg. 2019 Mar;45(3):351-354. doi: 10.1016/j.jcrs.2018.12.026

Accurate Axial Length

- Argos biometer (Alcon) measures sum-of-segments
  - It uses inaccurate refractive indices [1]
    - E.g., LT by this device is 0.22m thicker than OLCR [2]
    - This may make it different from other sum-of-segment ALs
  - It is different from other biometers
    - The impact is currently unclear though some IOL formulas calculate better with SOS-AL compared to traditional AL

1. Tamaoki A, Kojima T, Cooke DL. Conversion between the sum-of segments axial length and traditional axial length measured by optical biometry. J Cataract Refract Surg. 2021 Oct 16. doi: 10.1097/j.jcrs.0000000000000850. Epub ahead of print. PMID: 34670944
2. Shammas HJ, Ortiz S, Shammas MC, Kim SH, Chong C. Biometry measurements using a new large-coherence-length swept-source optical coherence tomographer. J Cataract Refract Surg. 2016 Jan;42(1):50-61. doi: 10.1016/j.jcrs.2015.07.042 Add to Citavi project by DOI. PMID: 26948778 Add to Citavi project by Pubmed ID.

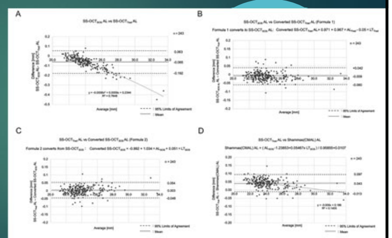
Comparison of SOS-AL with other AL Measurement Methods

- Mean difference between traditional AL and SOS-AL was only 0.065mm, but there was a marked slope: for long eyes, traditional AL was LONGER than SOS-AL
- Formula to convert to SOS-AL

Formula 1 converts to $SS\text{-}OCT_{SOS}$:

$$\text{Converted } SS - OCT_{Trad}\ AL = 0.971 + .967 \times AL_{Trad} - 0.05 \times LT_{Trad}$$

- But:
  - Is SOS-AL better for current IOL formulas?
  - Newer formulas have an internal mechanism to "adjust" for long AL already. Using SOS-AL may be "double dipping"



Improving AL Measurements ("Fudge Factors")

- Holladay 1 and Holladay 2 formulas have new AL adjusters that improve long eye predictions.

Linear Holladay 1 optimized-AL = 0.8048 × (OLCR-AL) + 4.9195

Linear Holladay 2 optimized-AL = 0.8332 × (OLCR-AL) + 4.2134

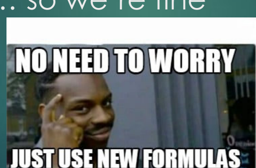
- SRK/T has a new Wang-Koch adjuster that improves long-eye predictions

Modified SRK/T optimized AL = 0.8453 × (measured AL) + 4.0773

Wang L, Koch DD. Modified axial length adjustment formulas in long eyes. J Cataract Refract Surg. 2018 Nov;44(11):1396-1397. doi: 10.1016/j.jcrs.2018.07.049. Epub 2018 Sep 28. PMID: 30274847.

Wang L, Holladay JT, Koch DD. Wang-Koch axial length adjustment for the Holladay 2 formula in long eyes. J Cataract Refract Surg. 2018 Oct;44(10):1291-1292. doi: 10.1016/j.jcrs.2018.06.057. Epub 2018 Aug 16. Erratum in: J Cataract Refract Surg. 2019 Jan;45(1):117. PMID: 30122353.

Well, that's all fine and dandy, but we use multivariable formulas that inherently adjust for AL and also incorporate values like ACD, CCT, LT, WTW… so we're fine



Interdevice Variability

- Does it matter which device you use to measure an eye before cataract surgery?
- Previous Studies:
  - Good agreement between the SS-OCT and OLCR biometers when using third-generation formulas [1,2]
- Our study (ASCRS 2022 Presentation): assess measurements on IOLM700 and Lenstar
  - All patients received both IOLM700 and LS scans sequentially at the same visit
  - **8,036 – 12,988** eyes depending on measured variable studied before eyes with warnings were removed
  - **3,331 – 4,866** eyes depending on measured variable studied after eyes with warnings were removed

1. Passi SF, Thompson AC, Gupta PK. Comparison of agreement and efficiency of a swept source-optical coherence tomography device and an optical low-coherence reflectometry device for biometry measurements during cataract evaluation. Clin Ophthalmol. 2018 Nov 1;12:2245-2251. doi: 10.2147/OPTH.S182898. PMID: 30464385;
2. Arriola-Villalobos P, Almendral-Gomez J, Garzon N, et al. Agreement and clinical comparison between a new swept-source optical coherence tomography-based optical biometer and an optical low-coherence reflectometry biometer. *Eye (Lond)* 2017;31:437-42.

Results: Mean K and AL

	All Eyes	No Alerts
	Mean K	Mean K
Difference ≥ 0.1 D	40.7%	53.5%
Difference ≥ 0.2 D	15.6%	17.4%
Difference ≥ 0.3 D	6.9%	6.3%
Difference ≥ 0.4 D	3.7%	2.6%
Difference ≥ 0.5 D	2.1%	1.3%
Difference ≥ 1D	0.3%	0.1%
N	8,036	3,331

	All Eyes	No Alerts
	AL	AL
Difference ≥ 0.1 mm	0.9%	0.6%
Difference ≥ 0.2 mm	0.3%	0.2%
Difference ≥ 0.3 mm	0.2%	0.1%
Difference ≥ 0.4 mm	0.2%	0.1%
Difference ≥ 0.5 mm	0.2%	0.1%
Difference ≥ 1 mm	0.2%	0.1%
N	12,988	4,866

59% and 63% of eyes were excluded with alerts for Mean K and AL respectively

Good news: 99.1% of ALs were within 0.01 mm, ~80% mean Ks within 0.5D

Results: CCT and ACD

- 63% of eyes were excluded with alerts for CCT and ACD

	All Eyes	No Alerts	All Eyes	No Alerts
	CCT	CCT	ACD	ACD
Difference ≥ 0.1 mm	40.5%	37.2%	63.9%	23.0%
Difference ≥ 0.2 mm	5.2%	3.5%	36.5%	19.5%
Difference ≥ 0.3 mm	1.0%	0.4%	19.8%	17.4%
Difference ≥ 0.4 mm	0.3%	0.0%	11.2%	15.0%
Difference ≥ 0.5 mm	0.1%	0.0%	6.6%	12.0%
Difference ≥ 1 mm	0.0%	0.0%	1.4%	0.8%
N	12,988	4,866	12,988	4,866

Differences in CCT after warnings were excluded showed a mild improvement.

Differences in ACD showed a drastic decrease in the difference at greater or equal to 0.1mm. Lenstar was estimating a 0.18 mm increase for ACD compared to IOLM in all eyes which changed to 0.13 mm increase when eyes that received alerts were excluded.

Results: AQD and LT

- 63% of eyes were excluded with alerts for AQD and LT

	All Eyes AQD	No Alerts AQD	All Eyes LT	No Alerts LT
Difference ≥ 0.1 mm	41.1%	23.4%	70.0%	52.2%
Difference ≥ 0.2 mm	31.2%	19.6%	59.2%	43.5%
Difference ≥ 0.3 mm	24.6%	17.7%	50.2%	37.3%
Difference ≥ 0.4 mm	19.1%	15.3%	41.1%	30.5%
Difference ≥ 0.5 mm	14.0%	12.2%	32.8%	24.4%
Difference ≥ 1 mm	0.9%	0.8%	8.3%	7.2%
N	12,988	4,866	12,988	4,866

LT: Lenstar averaged a 0.39 mm SHORTER LT compared to IOL in all eyes and a 0.30 mm SHORTER LT once eyes with alerts were excluded.

Bad news: 70% of LT differed by at least 0.10 mm (33% by at least 0.50mm)
41% of ACD differed by at least 0.10 mm (14% by at least 0.50mm)

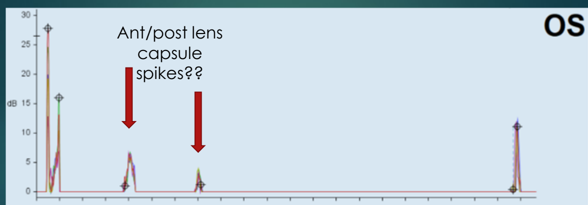
Interdevice Measurements: Takeaway Messages

- Considerable variability in specific optical path variables exists when measuring the same eyes with IOLM and LS biometry devices
- These differences may affect formula performance when using multivariable formulas that utilize ACD and LT, such as Olsen, Hill RBF, K6, Kane, etc.
- What is even more potentially challenging is that no "error" message may appear, so surgeons may not be aware of these inaccurately low LT values
- We sought to implement and evaluate a new program, SpikeFinder, which attempts to more accurately capture internal optical path measurements, specifically for LT and ACD measurements

Lens Thickness (LT)

- Utilized in newer formulas – Barrett, Kane, K6, Hill RBF, Olsen, etc.
- SpikeFinder (software program developed by David Cooke) to improve LT measurements with the LS
  - Best Paper Award at 2022 ASCRS Meeting
- We chose to study the eyes with the largest differences
  - 3197 eyes had LTs differing by at least 0.6 mm, 2471 of these could be analyzed using SpikeFinder

What Lies Beneath the Surface…?

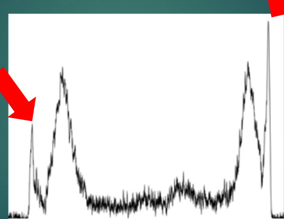


Measurement	CCT [µm]	AD [mm]	LT [mm]	RT [µm]	AL [mm]	
1	560	3.30	3.70	200**	23.78	☑
2	562	3.33	3.73	200**	23.79	☑
3	563	3.26	3.74	200**	23.78	☑
4	561	3.31	--------	200**	23.69	☑
5	560	3.35	3.67	200**	23.76	☑
Average	561 µm	3.31 mm	3.71 mm	200** µm	23.76 mm	
Standard dev.	1.5	0.034	0.031	0.0	0.039	

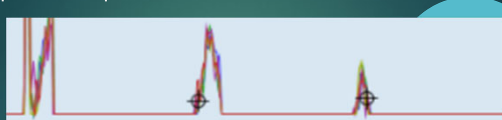
CCT Cornea thickness
AD Aqueous depth
LT Lens thickness
RT Retina thickness
AL Axial length

* Value user-defined
** System constant

Typical Lenstar Spike

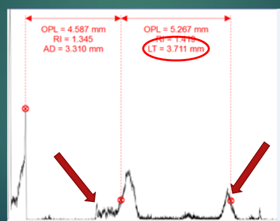


Beware of LT and ACD without capsular spikes



What Lies Beneath the Surface…? An Example of the Power of SpikeFinder

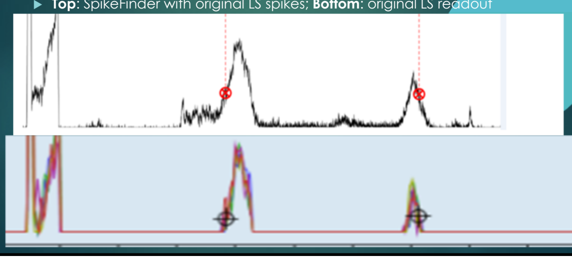
LT of 3.711 from original placement of cursors



anterior lens capsule was completely missed by the initial LS calculation!

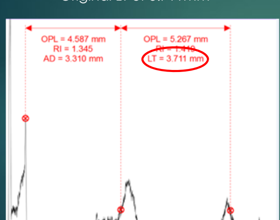
An Example of the Power of SpikeFinder

- **Top**: SpikeFinder with original LS spikes; **Bottom**: original LS readout

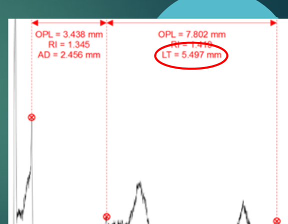


An Example of the Power of SpikeFinder

Original LT of 3.711mm

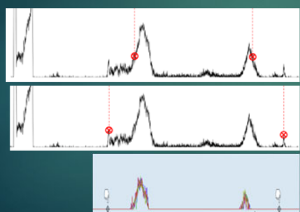


New LT of 5.497mm after SpikeFinder



Example #2 of SpikeFinder

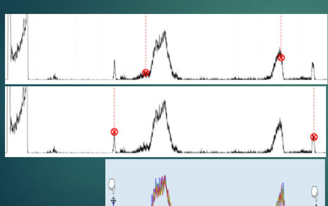
- **Top**: Original SpikeFinder with LS spikes;
  Middle: SpikeFinder readout after LS spike adjustment;
  Bottom: New spikes on original LS drawing



	ACD	LT
Original LS	3.31	3.71
LS After SF	2.46	5.50
IOLM700	2.42	5.54

Example #3 of SpikeFinder

- **Top**: Original SpikeFinder with LS spikes;
  Middle: SpikeFinder readout after LS spike adjustment;
  Bottom: New spikes on original LS drawing



	ACD	LT
Original LS	3.59	3.99
LS After SF	2.62	5.86
IOLM700	2.60	5.86

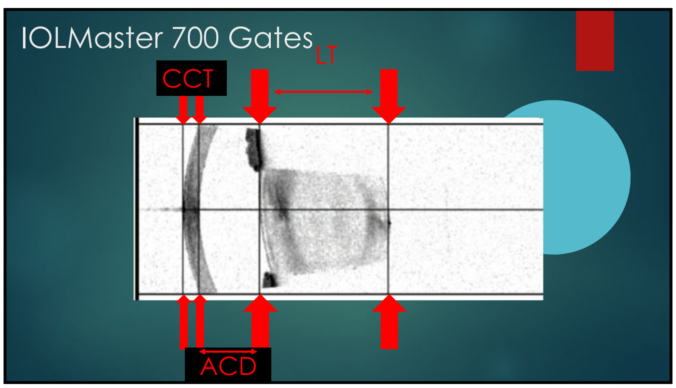
Summary of Results

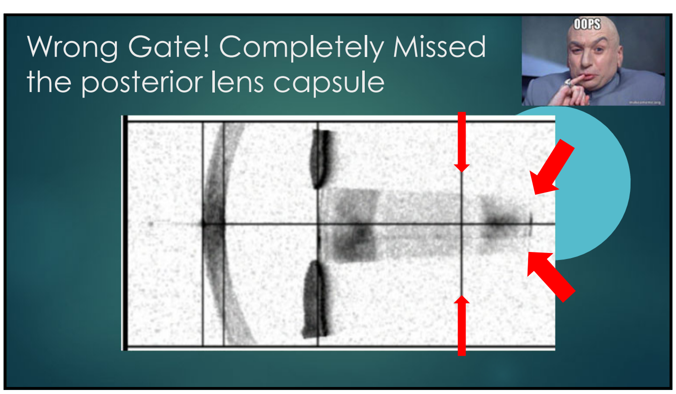
- SpikeFinder improves agreement between IOLM 700 and LS

IOLM 700 - Lenstar		
	ACD	LT
Mean (original)	-0.66	1.15
Mean (after SpikeFinder)	-0.03	0.06
SD (original)	0.31	0.38
SD after SpikeFinder)	0.05	0.2

- SF improves ACD/LT measurements obtained by Lenstar → improves accuracy of multivariable formulas
- Ironically, if one continues to use third-generation formulas that rely on ALs and K's, since LT is not used, IOL power calculated is same
  - But again, these formulas limited in extreme eyes


IOLM has limitations too…


IOLMaster 700 Gates
LT
CCT
ACD


Wrong Gate! Completely Missed the posterior lens capsule
OOPS

What Should I Do if I Have Bad LT Measurements?

- Have the patient return for repeat measurements?
  - Next section
- Practical: use formulas that don't require LT or ACD, especially if normal AL/K eyes
  - USE: traditional formulas (H1, HQ, SRK/T); T2, Ladas Super Surface Formula
  - DON'T USE: multivariable formulas

Are Repeat Biometry Measurements Helpful?

- Repeat 1,145 IOLMaster 700 scans taken from 2017-2021
- Variables for each scan received a "successful", "warning", or "failed" result for nine variables.
- Scans that received 9 "successful" results for 9 variables were considered "perfect scans".
- Repeated scans were analyzed to see if "warning" or "failed" results improved overall. Additionally, the variables LT, ACD, and keratometry were analyzed individually to see if "warning" or "failed" results improved on rescan(s).

Analysis of All Nine Variables of 1145 Re-scans		
Results of Re-Scans	Total Number of Re-scans (1145)	Percent
Identical	499	44%
Better	369	32%
Worse	277	24%

Identical or worse result in 68% of scans!

Analysis of All Nine Variables in 928 Re-scans After Excluding Perfect First Scans		
Results of Re-Scans	Total Number of Re-scans (928)	Percent
Identical	353	38%
Better	369	40%
Worse	206	22%

When analyzing all nine variables with a less-than-perfect first scan, the subsequent scan resulted in an identical or worse result in 60% of the scans.

But surely repeating the scans for eyes with bad LT measurements is good practice, right?

Analysis of the Variable LT When Either the Original or Re-scan Received a "Warning" or "Failed" Result		
Results of Re-Scans	Total Number (243)	Percent
Identical	88	36%
Better	89	37%
Worse	66	27%

- When analyzing the variable LT when the original scan or rescan received a "warning" or "failed" result, the subsequent scan resulted in an identical or worse result in 63% of the scans.

But repeating the scans for bad ACD measurements is good practice, right?

Results of Re-Scans	Total Number of Rescans (195)	Percent
Identical	58	30%
Better	80	41%
Worse	57	29%

- for eyes with "suspect" ACD values, the subsequent scan resulted in a similar or worse result in 59% of the scans.

But like we HAVE to repeat scans for bad K measurements, right

Results of Re-Scans	Total Number of Rescans (469)	Percent
Identical	146	31%
Better	205	44%
Worse	118	25%

- For eyes with "suspect" K measurements, repeat scan resulted in an identical or worse result in 56% of the scans

To rescan or not to rescan, that is the question?

- Rescanning resulted in identical or worse scan in ~2/3rd of subsequent scans, whether looking at all nine variables or isolating variables
- Even when looking at eyes that had a perfect first scan for one eye and a "bad" scan for the other eye, results for the rescan of the bad eye did not improve
- Rescans are not helpful in improving a "warning" or "failed" variable
- Logistical (economics, time, etc) burdens of rescans not worth the potential benefit of rescans

---

- So far, we have discussed AL, ACD, LT, etc
- Repeat measurements
- We have not discussed keratometry measurements (that was yesterday)

IOL Formulas: Categories

- Thin lens
- Thick lens
- Artificial Intelligence
- Ray-tracing
- Many formulas combine methods
- 24 Formulas (likely I have missed some)

IOL Formulas: International Effort!

- England
  - T2 richardsheard.net > T2formula
- France
  - Pearl DGS iolsolver.com
- Germany
  - Castrop iolcon.org/lpcm.php
  - Haigis
  - OKULIX prp@panopsis.de & www.okulix.de
- Korea
  - Eom EomIOLcalc.com
- Singapore
  - EVO 2.0 EvoIOLcalculator.com/calculator.aspx
- Ukraine
  - VRF
  - VRF-g
- Australia
  - Barrett Universal II APACRS.org
  - Kane IOLformula.com
- Costa Rica
  - Panacea PanaceaIOLandToricCalculator.com
- Denmark
  - Olsen PhacoOptics PhacoOptics.net
  - Olsen Biometer Biometer
  - Næser I
  - Næser II

IOL Formulas: USA Effort

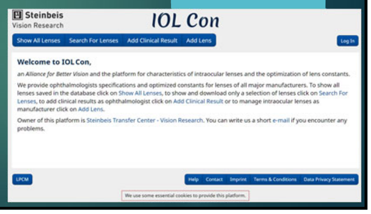
- USA
  - Hoffer
  - Hoffer QSTHofferQST.com
  - Holladay 1
  - Holladay 2 hicsoap.com
  - K6 CookeFormula.com
  - Ladas IOLcalc.com
  - RBF 3.0 RBFcalculator.com
  - SRK/T

New website

- One location for multiple formulas (~kayak.com)
  - ESCRS developing
    - Spearheading ophthalmologist: Dante Buonsanti
  - (Like ASCRS post-refractive surgery website)
  - Multiple, side-by-side comparison of formulas

New Lens Constants

- ULIB (User Group for Laser Interference Biometry)
  - http://ocusoft.de/ulib/c1.htm
  - Wolfgang Haigis
  - Last entry was 2016
- IOLcon
  - www.iolcon.org
  - Achim Langenbucher


Steinbeis
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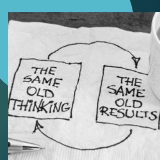
Formulas: Old Way of Thinking

- Use specific formulae for different axial lengths, because some formulae seemed to produce better outcomes in these subgroups
- Which Formula to use? (Hoffer JCRS 2000) = "Traditional Teaching"
  - 1. Short eyes (Holladay II or Hoffer Q)
  - 2. Normal eyes (22 to 24.5) => Average of Formulas
  - 3. Medium long eyes (24.5 to 26.0 mm) => Holladay I
  - 4. Long eyes (> 26.0 mm) => SRK/T, Holladay II
- Continues to be taught as "Gospel" in USA, UK, etc.[1-2]
- In 2000, we had flip phones, dial up internet, no Facebook
- With so many formulas → paradox of choice



1. Clinical Optics. Basic and Clinical Science Course, American Academy of Ophthalmology, 2020-2021
2. Cataracts in adults: management, NICE Guidelines, Published October 26, 2017. https://www.nice.org.uk/guidance/ng77/resources/cataracts-in-adults-management-pdf-1837639266757. Accessed April 1, 2021

Time to Upgrade!

Third-generation IOL formulas

Multivariable IOL formulas

Refractive outcomes of multivariable formulas

For Eyes with **Short**, normal, and long axial lengths

David Griffin, MD
David Cooke, MD
Kamran Riaz, MD

Dean McGee Eye Institute
The Preferred Eyecare Provider for the OKC Thunder

Presented (virtually) at ASCRS 2020,

Comparison of 21 Formulas

Which formula is most accurate?

- Single institution retrospective chart review -
  - **Short (< 22 mm)**
  - Normal (22-26 mm)
  - Long (>26 mm)
- Comparison of major IOL power formulas (21 total)
- IOL platform: SN60WF
- Biometer: Zeiss IOL Master 700 *(required for newer formulas)*
- Lens constant optimization

ALL Axial Lengths

MPE: actual SE – predicted SE

Formula performance for **ALL EYES** (mean axial length = 24 mm; from 20.6 to 30.91 mm) n = 400

Formula	MPE	MAE	MedAE	SD	Max AE	% +/- 0.5 D	% +/- 1.0 D
Evo 2.0	0.00	0.335	0.282	0.416	1.23	76.5%	98.8%
K-6	0.00	0.335	0.289	0.416	1.23	75.8%	98.5%
Kane	-0.00	0.338	0.279	0.420	1.25	75.8%	98.5%
Olsen-PhacoOptics	0.01	0.347	0.275	0.434	1.22	75.5%	98.0%
OKULIX	-0.00	0.348	0.285	0.433	1.25	73.8%	98.5%
Barrett	0.00	0.348	0.297	0.429	1.28	74.5%	98.5%
Hill RBF 2.0	0.00	0.351	0.310	0.431	1.42	76.2%	98.0%
H2 2020 w NLR	0.00	0.360	0.313	0.446	1.40	74.0%	97.3%
VRF	0.01	0.362	0.315	0.443	1.47	73.3%	98.3%
Olsen-Lenstar	-0.01	0.367	0.308	0.458	1.35	75.0%	97.0%
DGS	0.00	0.371	0.313	0.461	1.61	72.8%	97.5%
LADAS	0.00	0.371	0.328	0.459	1.58	73.8%	97.8%
Næser w opt	0.00	0.371	0.329	0.457	1.47	73.0%	97.5%
Næser no opt	0.00	0.372	0.331	0.458	1.45	72.5%	97.8%
T2	0.00	0.373	0.329	0.459	1.76	71.8%	97.0%
H-1 (2018 Wang-Koch)	-0.00	0.375	0.340	0.458	1.68	72.0%	97.0%
SRK/T	0.00	0.383	0.341	0.471	1.77	71.5%	97.0%
Haigis	0.00	0.385	0.342	0.473	1.58	70.8%	97.0%
Holladay 2 (2014)	0.00	0.392	0.330	0.480	1.51	68.8%	97.0%
Holladay 1	-0.00	0.404	0.341	0.506	1.78	68.5%	95.3%
Hoffer Q	-0.00	0.434	0.370	0.537	1.80	63.0%	94.8%

Adjust until MPE = zero = optimization

Percent eyes within

+/- 0.5 D prediction

+/- 1.0 D prediction

Cochrane Q test

ALL Axial Lengths

Formula performance for **ALL EYES** (mean axial length = 24 mm; from 20.6 to 30.91 mm) n = 400

Formula	MPE	MAE	MedAE	SD	Max AE	% +/- 0.5 D	% +/- 1.0 D
Evo 2.0	0.00	0.335	0.282	0.416	1.23	76.5%	98.8%
K-6	0.00	0.335	0.289	0.416	1.23	75.8%	98.5%
Kane	-0.00	0.338	0.279	0.420	1.25	75.8%	98.5%
Olsen-PhacoOptics	0.01	0.347	0.275	0.434	1.22	75.5%	98.0%
OKULIX	-0.00	0.348	0.285	0.433	1.25	73.8%	98.5%
Barrett	0.00	0.348	0.297	0.429	1.28	74.5%	98.5%
Hill RBF 2.0	0.00	0.351	0.310	0.431	1.42	76.2%	98.0%
H2 2020 w NLR	0.00	0.360	0.313	0.446	1.40	74.0%	97.3%
VRF	0.01	0.362	0.315	0.443	1.47	73.3%	98.3%
Olsen-Lenstar	-0.01	0.367	0.308	0.458	1.35	75.0%	97.0%
DGS	0.00	0.371	0.313	0.461	1.61	72.8%	97.5%
LADAS	0.00	0.371	0.328	0.459	1.58	73.8%	97.8%
Næser w opt	0.00	0.371	0.329	0.457	1.47	73.0%	97.5%
Næser no opt	0.00	0.372	0.331	0.458	1.45	72.5%	97.8%
T2	0.00	0.373	0.329	0.459	1.76	71.8%	97.0%
H-1 (2018 Wang-Koch)	-0.00	0.375	0.340	0.458	1.68	72.0%	97.0%
SRK/T	0.00	0.383	0.341	0.471	1.77	71.5%	97.0%
Haigis	0.00	0.385	0.342	0.473	1.58	70.8%	97.0%
Holladay 2 (2014)	0.00	0.392	0.330	0.480	1.51	68.8%	97.0%
Holladay 1	-0.00	0.404	0.341	0.506	1.78	68.5%	95.3%
Hoffer Q	-0.00	0.434	0.370	0.537	1.80	63.0%	94.8%

18 formulas were > 70% within 0.5D
Best and worst only 13% difference

STRONG

GOOD

MODERATE

FAIR

"Traditional Teaching"

- A commonly held teaching is that Hoffer Q, Holladay 1, and SRK/T formulas offer the most accurate outcomes for short, normal and long AL eyes, respectively.[1]
- This recommendation has become a part of residency curriculum for ophthalmology trainees and ophthalmic society recommendations in the United States, Canada, and the United Kingdom, despite the availability of newer multivariable IOL formulas.[2-6]
- So how did this Traditional Teaching perform in long and short AL eyes in our dataset?

1. Aristodemou P, Knox Cartwright NE, Sparrow JM, Johnston RL. Formula choice: Hoffer Q, Holladay 1, or SRK/T and refractive outcomes in 8108 eyes after cataract surgery with biometry by partial coherence interferometry. J Cataract Refract Surg 2011; 37(1):63-71.
2. Clinical Optics. Basic and Clinical Science Course, American Academy of Ophthalmology, 2020-2021
3. Gale RP, Saha N, Johnston RL. National biometry audit. Eye (Lond). 2004; 18(1):63-66.
4. Gale RP, Saha N, Johnston RL. National Biometry Audit II. Eye (Lond). 2006; 20(1):25-28.
5. The Royal College of Ophthalmologists Cataract Surgery Guidelines. https://www.rcophth.ac.uk/wp-content/uploads/2014/12/2010-SCI-069-Cataract-Surgery-Guidelines-2010-SEPTEMBER-2010-1.pdf. Accessed April 1, 2021
6. Cataracts in adults: management, NICE Guidelines, Published October 26, 2017. https://www.nice.org.uk/guidance/ng77/resources/cataracts-in-adults-management-pdf-1837639266757. Accessed April 1, 2021

LONG Axial Lengths

Formula performance for **LONG EYES** (mean axial length = 27.56 mm; from 26.02 to 30.91 mm) n = 34

Formula	MPE	MAE	MedAE	SD	Max AE	% +/- 0.5 D	% +/- 1.0 D
K-6	-0.03	0.318	0.309	0.380	0.79	82.4%	100.0%
Olsen-PhacoOptics	0.10	0.318	0.330	0.366	0.85	85.3%	100.0%
Olsen-Lenstar	0.11	0.319	0.325	0.365	0.86	85.3%	100.0%
Næser w opt	0.08	0.321	0.294	0.379	0.76	73.5%	100.0%
Hill RBF 2.0	0.14	0.323	0.295	0.367	0.84	79.4%	100.0%
Evo 2.0	0.14	0.326	0.295	0.368	0.93	76.5%	100.0%
H2 2020 w NLR	-0.13	0.326	0.290	0.381	0.93	79.4%	100.0%
H-1 (2018 Wang-Koch)	0.04	0.330	0.335	0.391	0.68	70.6%	100.0%
Kane	0.17	0.330	0.267	0.367	0.93	73.5%	100.0%
Næser no opt	0.14	0.337	0.290	0.381	0.84	70.6%	100.0%
OKULIX	0.22	0.349	0.311	0.370	0.97	71.4%	100.0%
Barrett	0.16	0.373	0.347	0.402	0.82	70.6%	100.0%
T2	0.21	0.375	0.328	0.404	1.00	64.7%	97.1%
VRF	0.12	0.380	0.337	0.433	0.85	67.6%	100.0%
Haigis	0.26	0.392	0.333	0.397	1.04	67.6%	97.1%
LADAS	0.26	0.397	0.379	0.404	1.05	67.6%	97.1%
SRK/T	0.25	0.496	0.473	0.507	[illegible]	52.9%	97.1%
DGS	0.46	0.524	0.503	0.433	1.38	50.0%	91.2%
Holladay 2 (2014)	0.51	0.570	0.567	0.429	1.43	47.1%	88.2%
Hoffer Q	0.63	0.669	0.674	0.434	1.53	38.2%	79.4%
Holladay 1	0.63	0.701	0.760	0.521	1.78	32.4%	76.5%

Much bigger difference between newer and older formulas

Note the poor performance of SRK/T

STRONG

GOOD

MODERATE

FAIR

SHORT Axial Lengths

Formula performance for **SHORT EYES** (mean axial length = 21.44 mm; from 20.6 to 21.94 mm) n = 40

Formula	MPE	MAE	MedAE	SD	Max AE	% +/- 0.5 D	% +/- 1.0 D
K-6	0.02	0.297	0.228	0.378	0.79	77.5%	100.0%
Evo 2.0	0.00	0.308	0.266	0.384	0.92	80.0%	100.0%
OKULIX	-0.10	0.332	0.281	0.413	0.90	75.6%	100.0%
Olsen-PhacoOptics	-0.06	0.341	0.260	0.427	0.97	72.5%	100.0%
Kane	-0.09	0.343	0.275	0.399	0.88	75.0%	100.0%
H2 2020 w NLR	0.16	0.349	0.255	0.435	1.40	77.5%	95.0%
Hill RBF 2.0	-0.05	0.359	0.328	0.441	1.15	77.5%	97.5%
SRK/T	-0.02	0.359	0.308	0.469	1.28	67.5%	97.5%
VRF	-0.14	0.361	0.331	0.425	1.10	65.0%	97.5%
Barrett	-0.13	0.378	0.319	0.450	1.12	70.0%	95.0%
Olsen-Lenstar	0.12	0.393	0.353	0.488	1.28	72.5%	97.5%
T2	-0.15	0.398	0.316	0.459	1.13	70.0%	97.5%
Næser w opt	-0.07	0.399	0.383	0.462	1.05	67.5%	97.5%
DGS	-0.26	0.400	0.349	0.381	0.92	72.5%	100.0%
Næser no opt	-0.14	0.407	0.393	0.459	0.99	60.0%	100.0%
Haigis	-0.06	0.410	0.410	0.467	1.07	62.5%	97.5%
H-1 (2018 Wang-Koch)	-0.18	0.414	0.387	0.452	1.06	67.5%	97.5%
Holladay 2 (2014)	-0.27	0.418	0.448	0.418	0.95	60.0%	100.0%
LADAS	-0.27	0.427	0.361	0.458	1.53	75.0%	92.5%
Holladay 1	-0.25	0.434	0.436	0.451	1.01	65.0%	97.5%
Hoffer Q	-0.54	0.604	0.643	0.446	1.39	35.0%	87.5%

Again same lesson: newer formulas are superior to old formulas

Note the poor performance of Hoffer Q

STRONG

GOOD

MODERATE

FAIR

But…What About Hoffer Q?

- Prior studies have shown Hoffer Q results are much better when lens constant optimization is exclusively done for short eyes[1,2]
- For example, in our dataset, when optimized only for short AL eyes, the Hoffer Q personalized ACD was 5.445, as opposed to 5.725 when optimized for all AL eyes.
  - Hoffer formula used in our study was verified by Hoffer himself (personal communication between Hoffer and Cooke)
- Using optimized values improved Hoffer Q from last position to 9th position for short ALs
- But… this required 3 years of searching eligible cases for 40 eyes at large eye institute to find this volume of short AL eyes utilizing a single IOL platform with same biometry. Most surgeons will likely be unable to perform this optimization due to the paucity of short AL eyes.
- Logistical difficulties may exist with training ancillary staff to use the "short AL" optimized Hoffer Q ACD for short AL eyes only and a different ACD for all other AL eyes.

1. Shrivastava AK, Behera P, Kumar B, Nanda S. Precision of intraocular lens power prediction in eyes shorter than 22 mm: An analysis of 6 formulas. J Cataract Refract Surg. 2018; 44:1317-20. doi: 10.1016/j.jcrs.2018.07.023.
2. Sudhakar S, Hill DC, King TS, Scott IU, Mishra G, Ernst BB, et al. Intraoperative aberrometry versus preoperative biometry for intraocular lens power selection in short eyes. J Cataract Refract Surg 2019; 45(6):719-24. doi: 10.1016/j.jcrs.2018.12.016.

Summarized Recommendations Re: Formulas

- Long Eyes (<27.5mm): EVO, Kane, K6, and Olsen
- Short Eyes (<21.5mm): Kane, K6, EVO
- All others (safety of machine auto-entry):
  - Barrett
  - Holladay 1
  - SRK/T

Other big take away: ABANDON Traditional Teaching!!

Take Away Messages

- Manually inputting measurements into online calculators **should be considered for extreme AL eyes**, especially for short AL eyes and for surgeons who lack access to multivariable formulas integrated into biometry devices
- multiple newer online-only or biometry-integrated formulas offer superior predictability for short and long AL eyes when compared to Hoffer Q and SRK/T.
- We propose that this "Traditional Teaching" should therefore by critically evaluated and reconsidered → please stop using HofferQ for short eyes
- In the future, we may be able to determine the "**perfect trifecta**":

combination of biometry device + IOL platform + IOL formula works best for extreme AL eyes

Current Practices (Caveat Emptor)

- Current practice (Oct 2021) –
  - Measurements taken with both Lenstar and IOL Master
  - iTrace and Pentacam topography for >1.5D astigmatism
  - For normal eyes: comparison of 5 formulas: Barrett, Hill RBF, Holladay I, Olsen, Holladay 2 (all available on the biometry printouts)
  - For long eyes: Kane, K6 and EVO (input into online)
  - For short eyes: Hill RBF, K6 and EVO; ?Castrop
  - If you could only have ONE formula: EVO 2.0 or K6 (www.cookeformula.com and https://www.evoiolcalculator.com/calculator.aspx)
  - Still trying to optimize flat and steep K eyes…

Final Conclusions

- We have to pay attention to preoperative measurements
- Must abandon old habits and practices
- No one-size-fits-all/ Swiss army knife IOL formula: we are still chasing the elusive perfect IOL formula
- Rapidly changing field: must keep current with data and **evidenced-based literature** rather than "ABBL" anecdotal and bravado based literature, and consider costs incurred with newer technologies

THANK YOU

- Ideal Universe: perfect biometry device + perfect IOL platform + perfect IOL formula = best outcomes
- Questions/Comments?